

## WR25 & WR140 in X-ray relation to $\eta$ Carinae

with data from  
**RXTE, Swift XRT, XMM-Newton EPIC-MOS, Chandra HETG**

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G2G with WR140

Dougherty (CA), Hamaguchi (US), Moffat (CA), Pittard (UK), Williams (UK)

**JD13@IAUXXVII General Assembly : 2009 August 14**

# X-ray bright ☀+☀ Wolf-Rayet binaries

## ☀+☀ WR 25

☀+☀ η Carinae's next-door neighbour

☀+☀  $V = 7^m$

☀+☀ WN6ha+O

☀+☀ Gamen+ optical radial velocity orbit

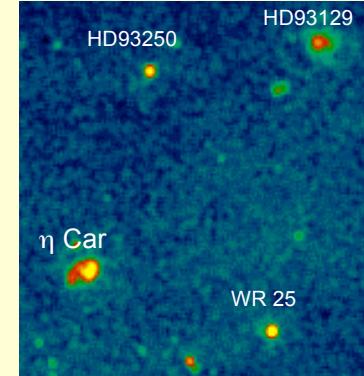
☀+☀  $P = 0.569$  years

☀+☀  $e = 0.595$

☀+☀  $\text{asini} = 2.4$  AU

☀+☀  $T_0, \omega$ , etc.

η Car



## ☀+☀ WR 140

☀+☀  $V = 7^m$  in Cygnus

☀+☀ WC7+O5

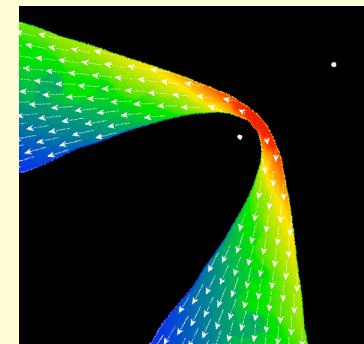
☀+☀ Marchenko+ optical radial velocity orbit

☀+☀  $P = 7.94$  years

☀+☀  $e = 0.881$

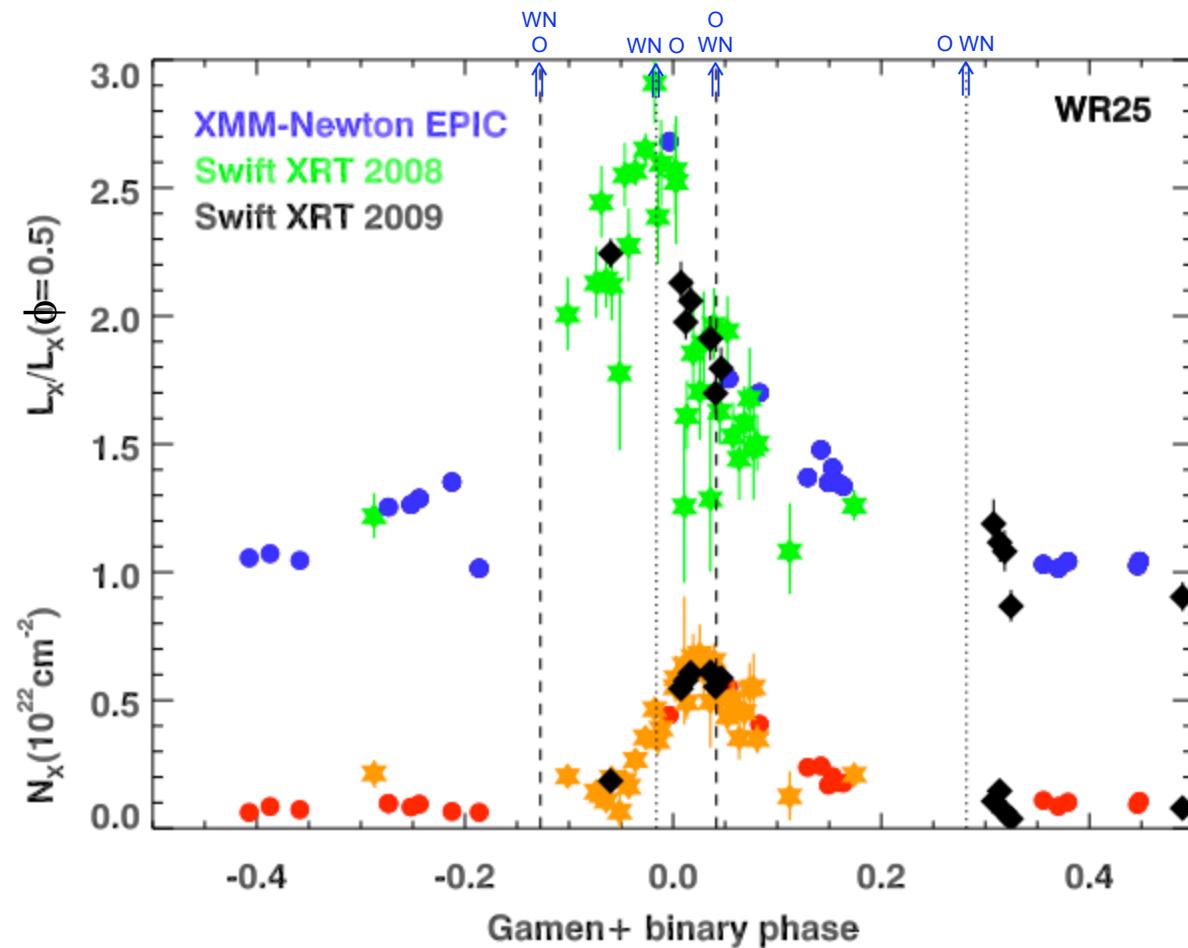
☀+☀  $\text{asini} = 14.1$  AU

☀+☀  $T_0, \omega$ , etc.



## WR 25's $L_x$ - $N_x$ history

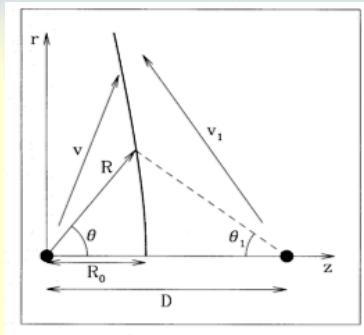
XSPEC> model const( $\phi$ )\*abs( $\phi$ )\*S<sub>x</sub>\*ISM



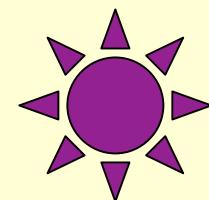
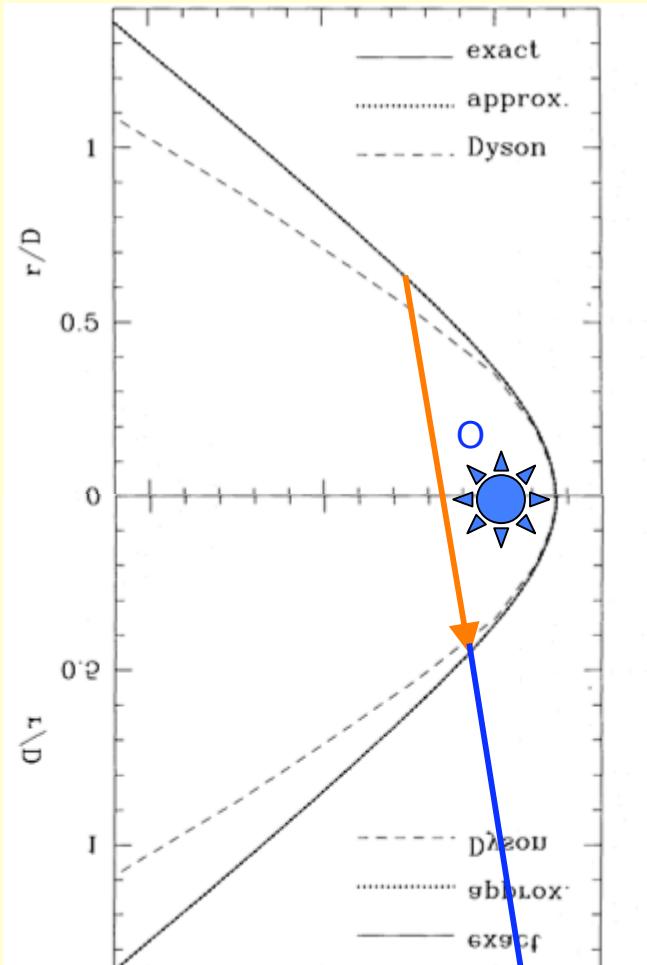
## Ingredients for a tractable X-ray model of WR 25

- Gamen+'s optical radial velocity orbit
- orbital inclination
- WN6ha stellar parameters
  - mass-loss rate
  - abundances
  - wind velocity
  - stellar radius
- O stellar parameters
  - mass-loss rate
  - abundances
  - wind velocity
  - stellar radius
- X-ray emitting surface
  - **not a point source** ⇒ Cantó, Raga & Wilkin (1996)
- Empirical  $L_X(D)$
- 50-parameter xspec local model
  - 77 XMM EPIC-MOS and Swift XRT spectra
    - 3850 parameters

## Cantó, Raga and Wilkin (1996) surface



$$\theta_1 \cot \theta_1 = 1 + \beta(\theta \cot \theta - 1)$$



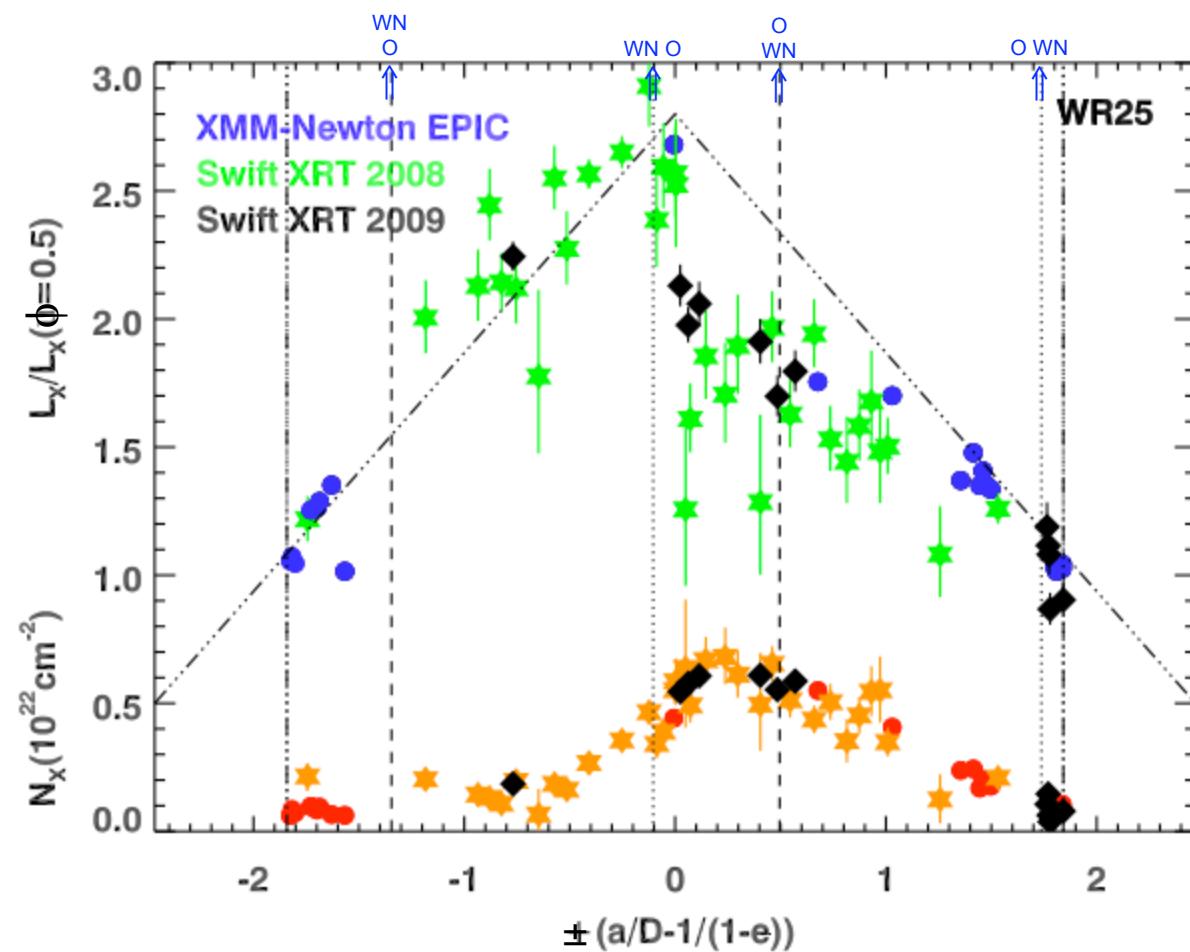
WN6ha

- ⊖ no Coriolis forces
- ⊖ not a thin shell

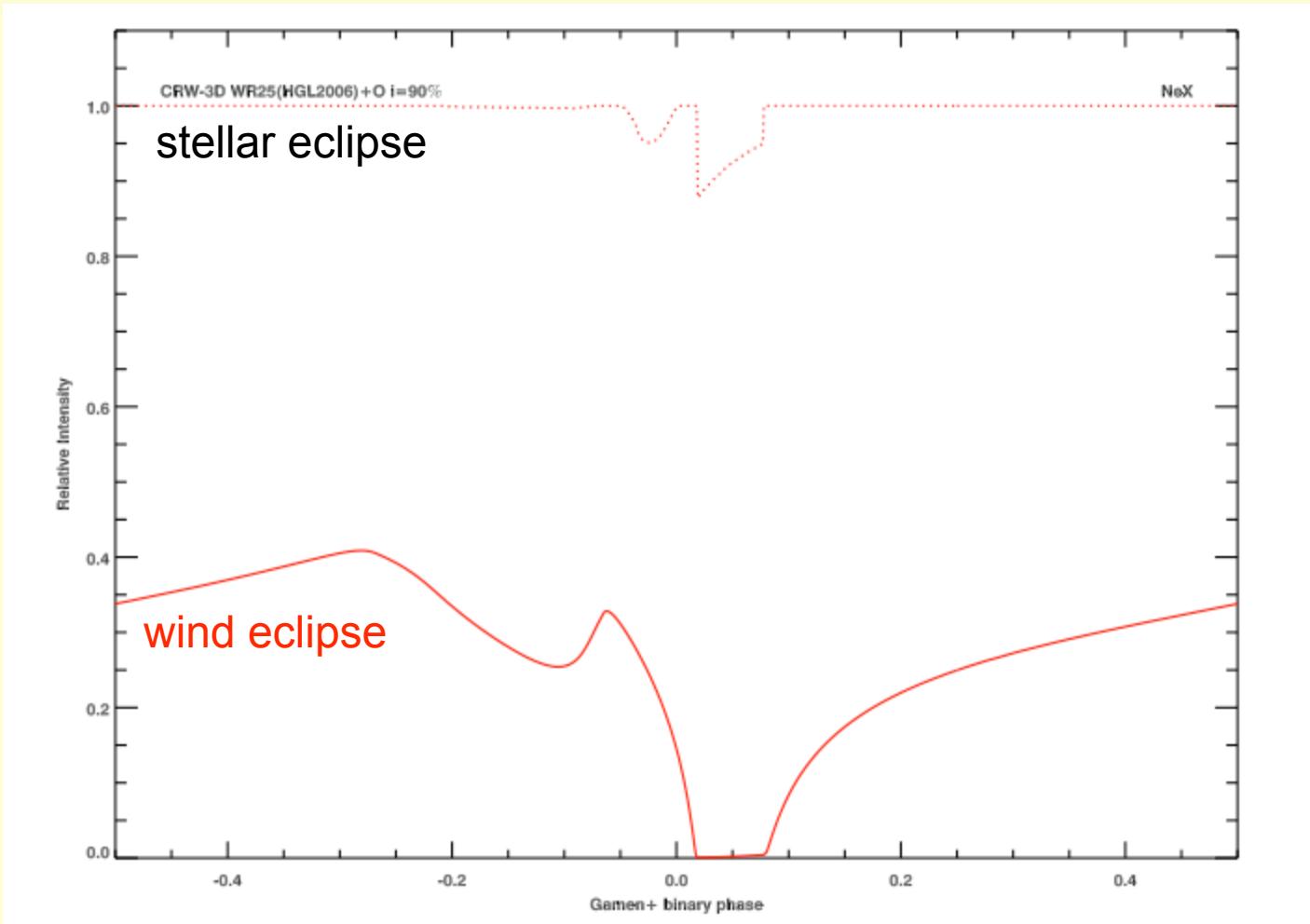
- 2D  $\Rightarrow$  3D
- WR-star
  - absorption
  - eclipse
- O-star
  - absorption
  - eclipse
- line velocity profiles

## Change of variable $\Rightarrow L_x(D)$ (cf CWB 1/D)

XSPEC> model const( $\phi$ )\*abs( $\phi$ )\*S<sub>x</sub>\*ISM



## CRW-3D eclipse and 1keV absorption in WR 25

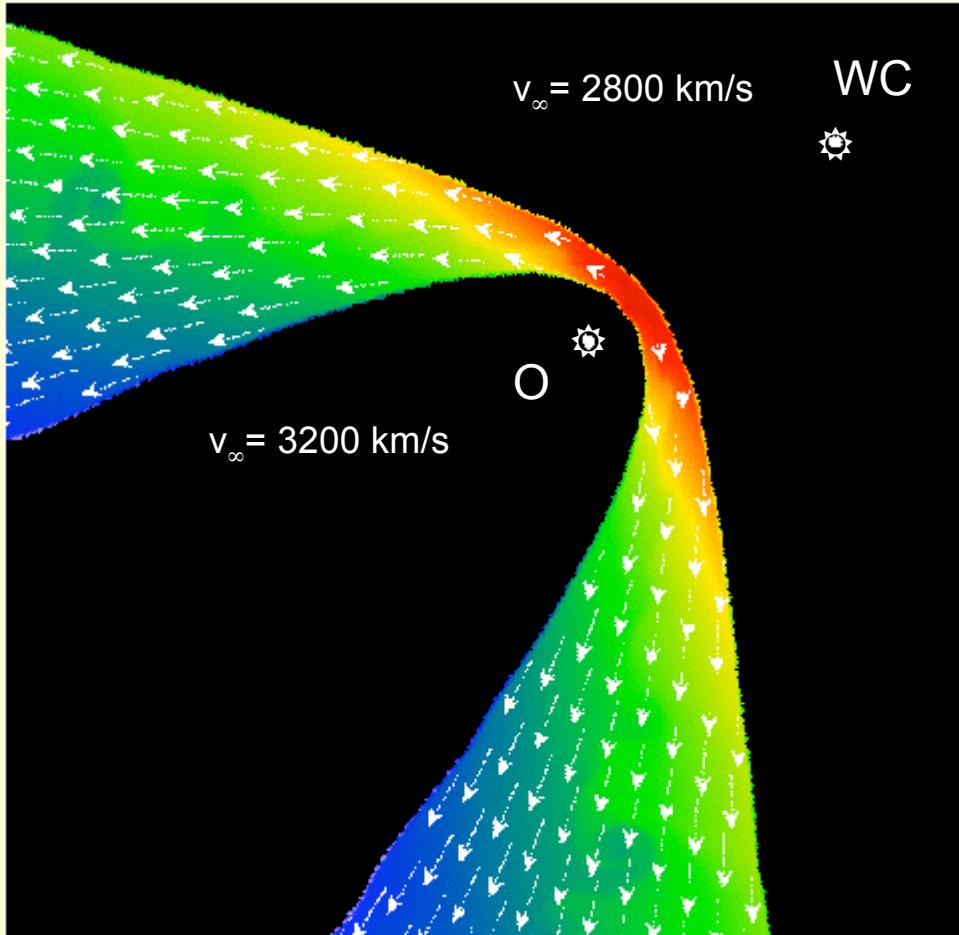


## CRW-3D “minimum” radius for WR 25

- $R_{WN6ha} \geq 49 R_\odot$  (50% higher than HGL(2006))
- $dM/dT = 2.7 \times 10^{-6} M_\odot \text{yr}^{-1}$  (20x lower than HGL(2006))
- inclination fixed at  $90^\circ$
- Gamen+ orbital parameters relaxed
- C-statistic = 36505.65 using 44139 bins and 44131 degrees of freedom

## WR140's colliding-wind shocks

colliding winds  $\Leftrightarrow$  counter-streaming plasma flows  $\Leftrightarrow$  well-known boundary conditions  $\{\mu, n, v, T\}$



Stevens, Blondin & Pollock (1992) numerical hydrodynamics

X-rays from WR 25 & WR 140  
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## WR140's 2-10 keV X-rays with *RXTE*

D~2AU  
 $n > 10^8 \text{ cm}^{-3}$

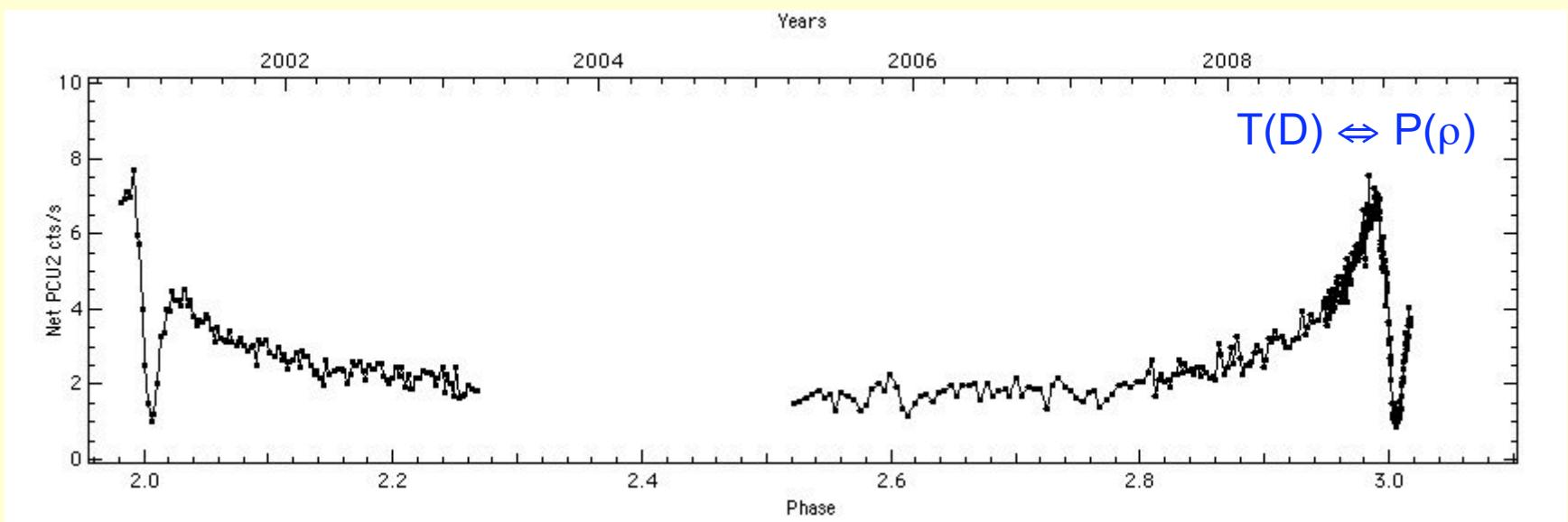
D~30AU  
 $n < 10^6 \text{ cm}^{-3}$

D~2AU  
 $n > 10^8 \text{ cm}^{-3}$

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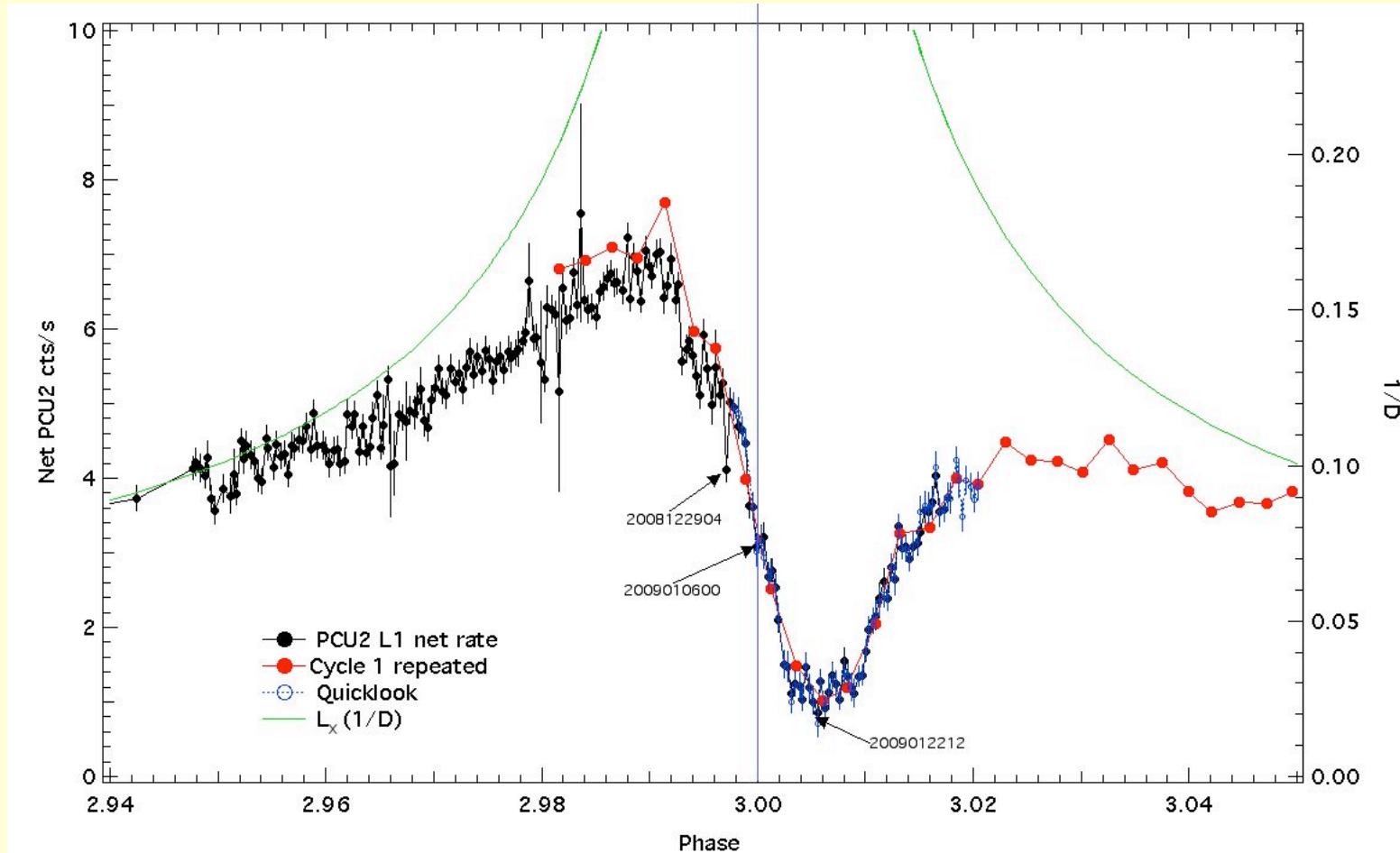
### X-rays at low resolution

X-rays from WR 25 & WR 140  
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## WR140 with RXTE through the 2009 event



X-rays at low resolution

X-rays from WR 25 & WR 140  
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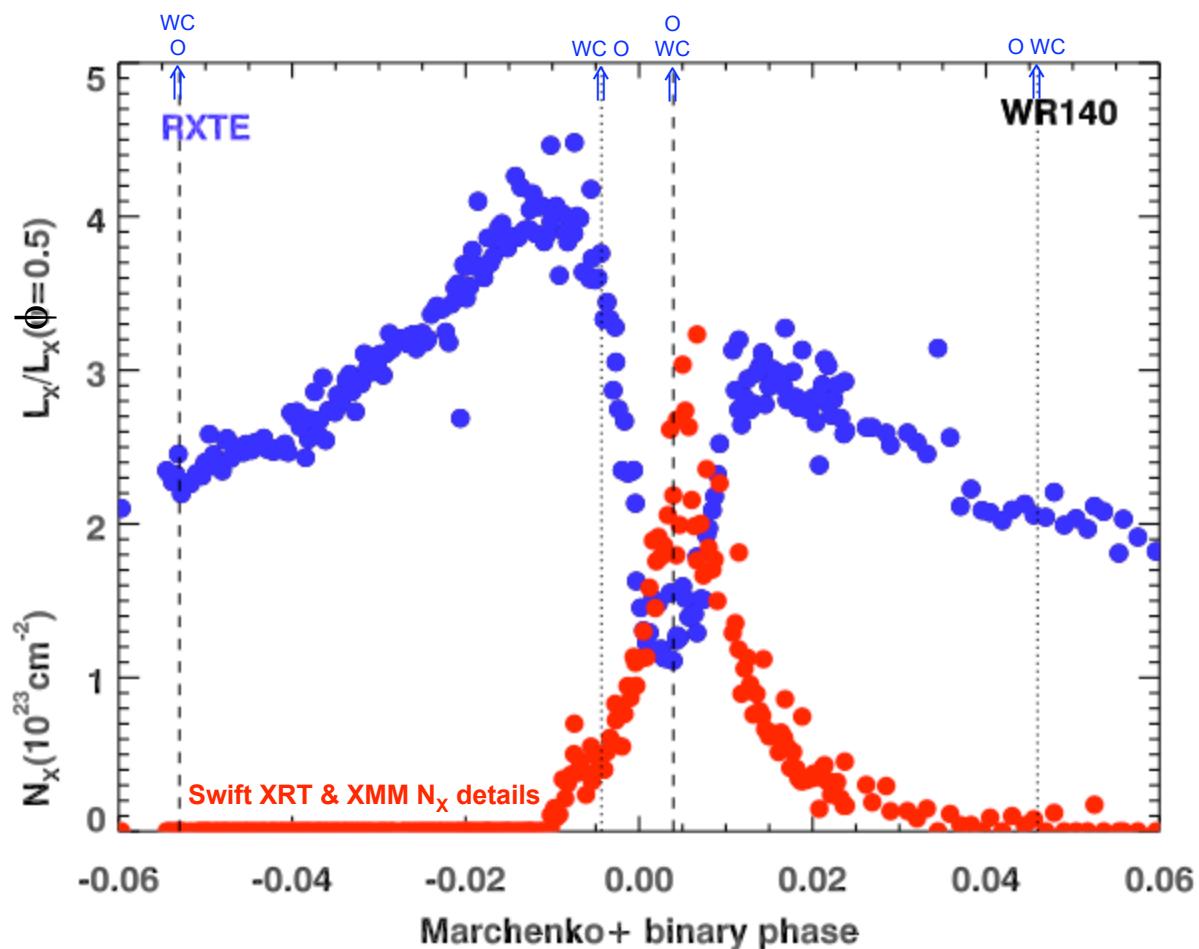
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Also Swift XRT, Suzaku & XMM

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## WR140 with *RXTE* through the 2009 event

XSPEC> model const( $\phi$ )\*abs( $\phi$ )\*S<sub>x</sub>\*ISM



X-rays at low resolution

$N_x(\text{WR140}) > 50 N_x(\text{WR25})$

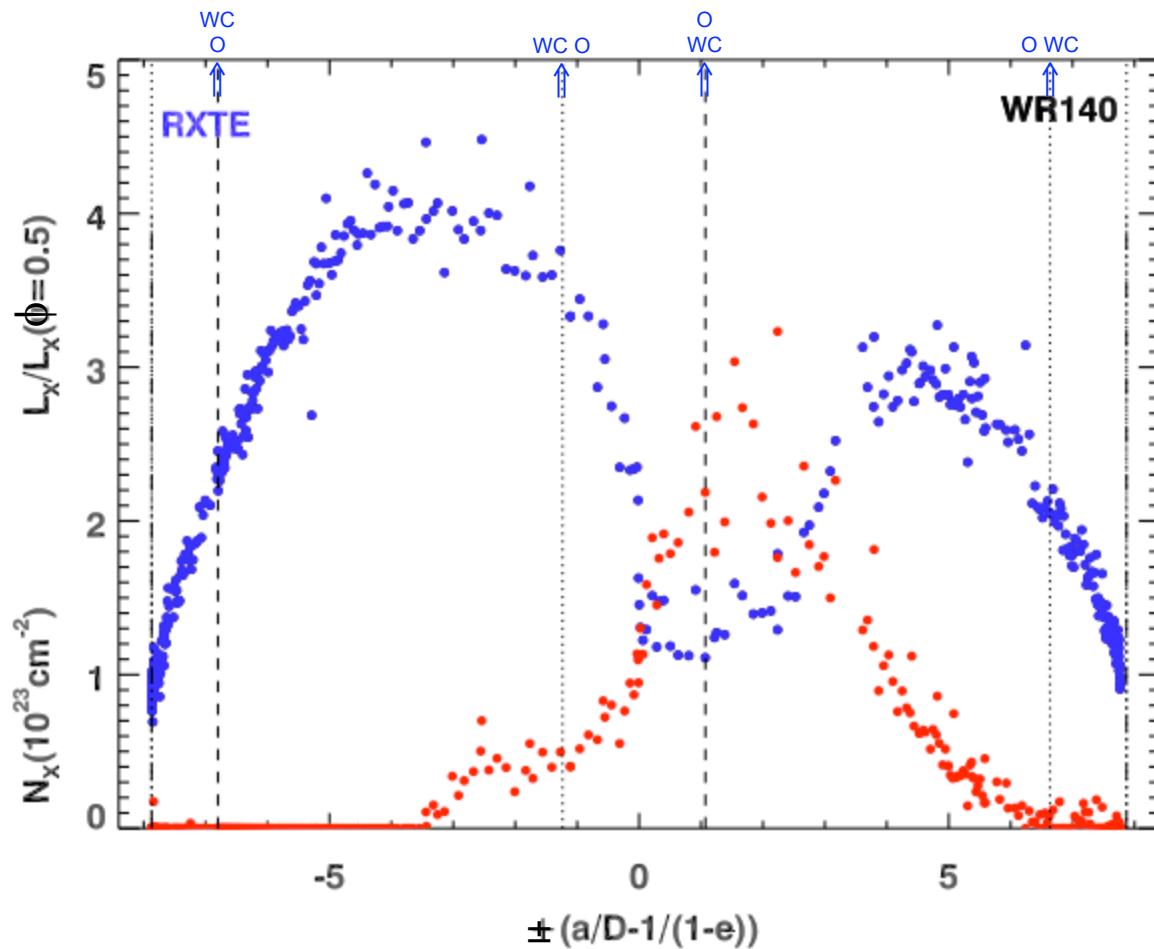
X-rays from WR 25 & WR 140  
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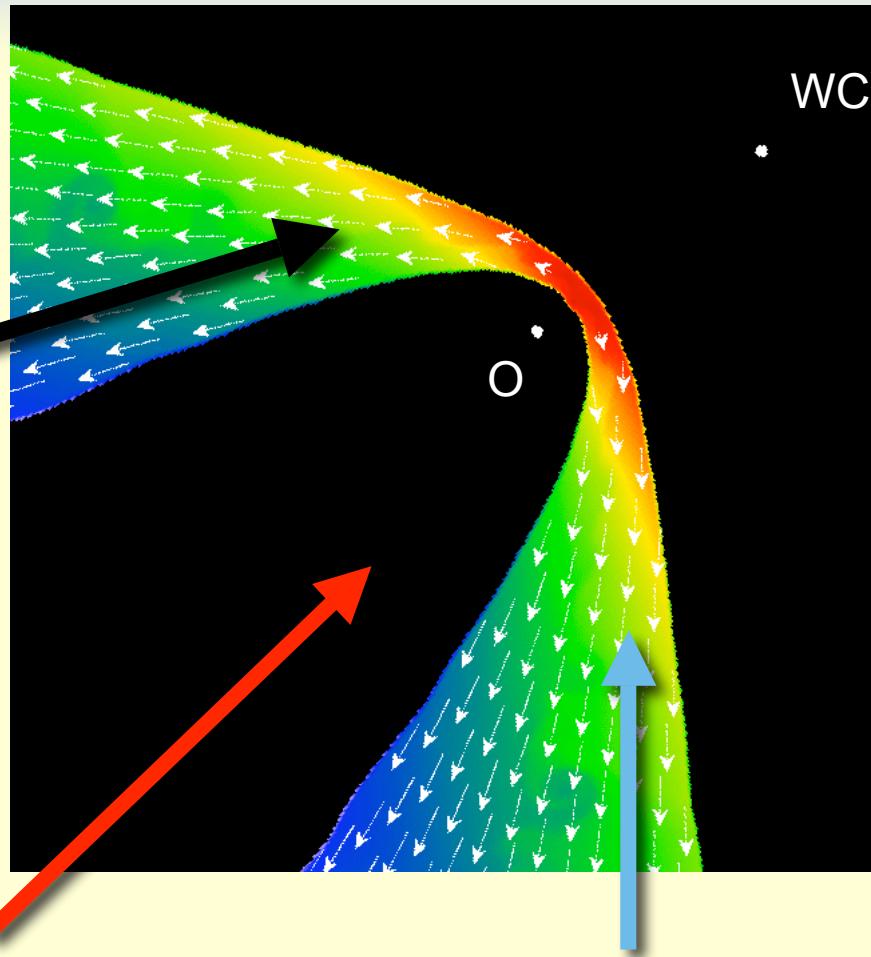
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## Change of variable $\Rightarrow L_x(D)$ (cf CWB 1/D)

XSPEC> model const( $\phi$ )\*abs( $\phi$ )\*S<sub>x</sub>\*ISM



## Chandra phase-dependent grating spectra of WR140

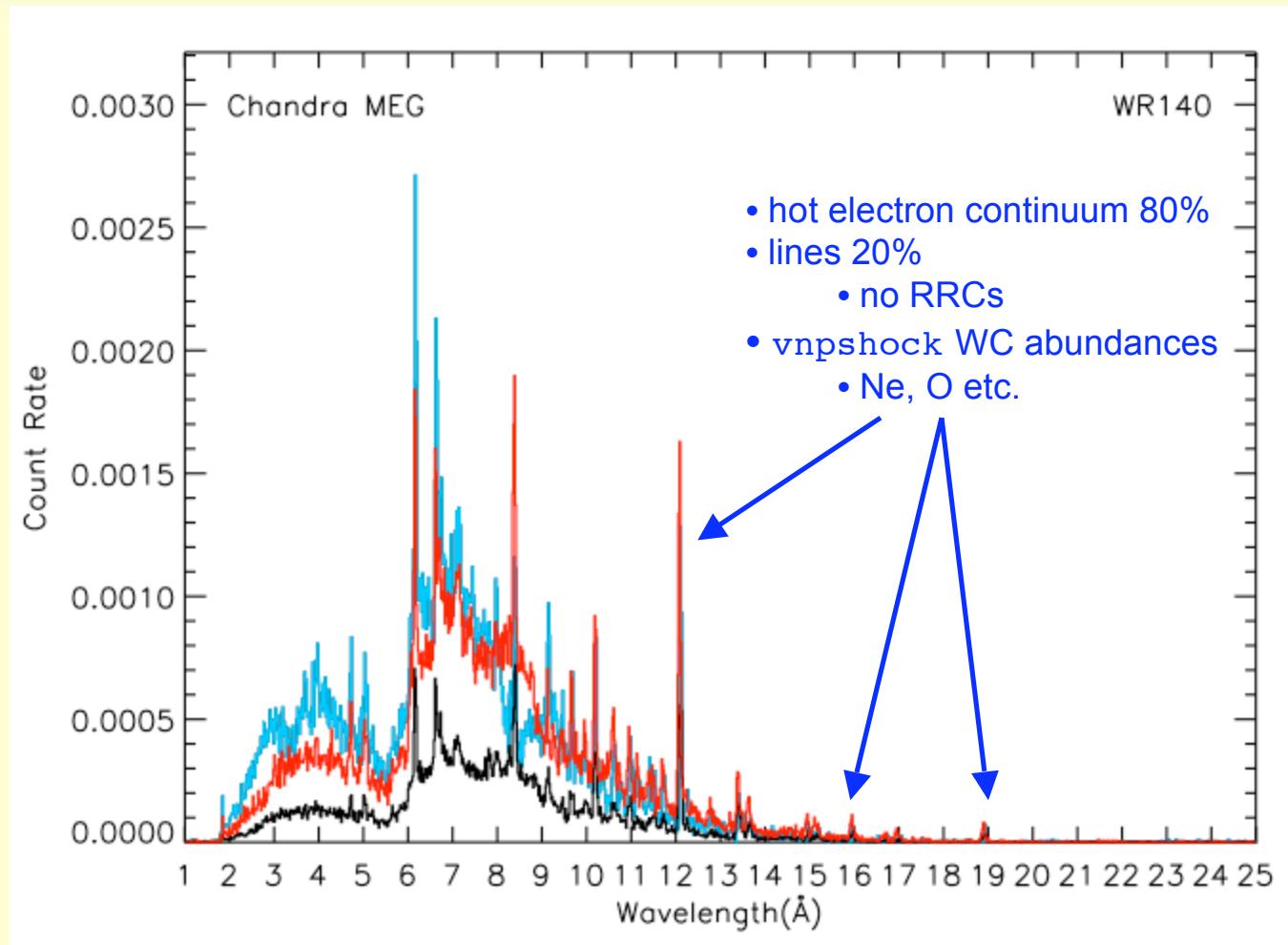


X-rays from WR 25 & WR 140  
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## Chandra phase-dependent spectra of WR140



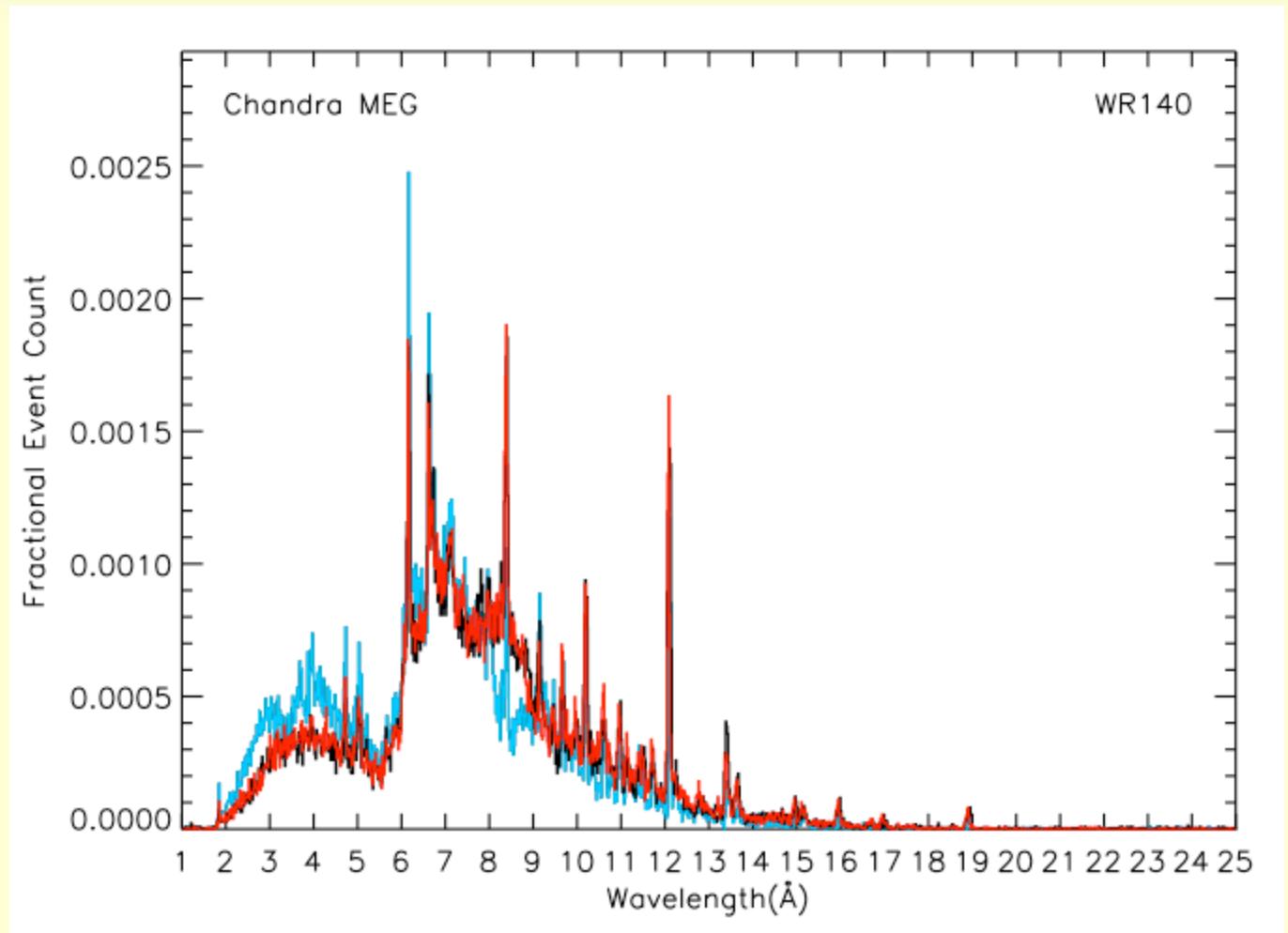
### X-rays at high resolution

X-rays from WR 25 & WR 140  
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## Chandra normalised spectra of WR140



X-rays at high resolution

X-rays from WR 25 & WR 140  
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## WR140's shock and post-shock physics

❖+❖ Spitzer ⊕ Zel'dovich & Raizer Coulomb-collisional arguments

❖+❖  $I_{\text{ion-ion}} \approx 14(D/a)^2 \text{ AU} \Rightarrow \text{collisionless shocks}$

❖+❖  $I_{\text{ion-electron}} \approx 21(D/a)^2 \text{ AU} \Rightarrow \text{free electron heat up slowly}$

❖+❖  $I_{\text{ionization}} \approx 8(D/a)^2 \text{ AU} \Rightarrow \text{bounds electrons freed slowly}$

❖+❖ WR140's spectrum looks like a collisional plasma

❖+❖ Coulomb collisions are not enough

❖+❖ plasma physics  $\Leftrightarrow \underline{B}$

❖+❖ Alfvén waves

❖+❖ wave-particle interactions

❖+❖ Weibel instability

❖+❖ two-stream instability

❖+❖  $\neg$ equilibrium

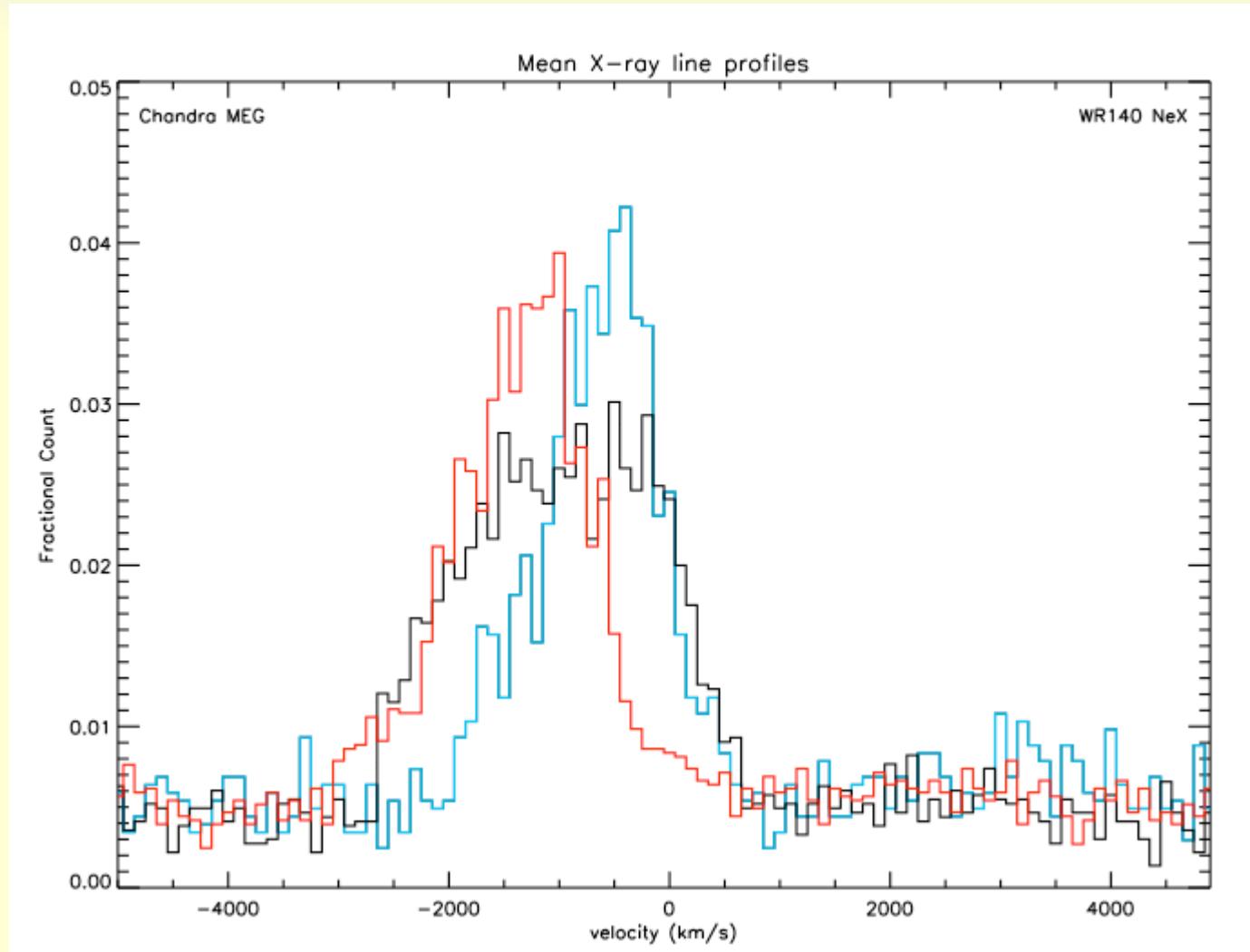
❖+❖ charge exchange

❖+❖ no ionization precursor

❖+❖ cf SNR & solar wind  $\nearrow$  magnetosphere

## Chandra X-ray NeX line profiles

cf Henley+ (2003) and CRW-3D



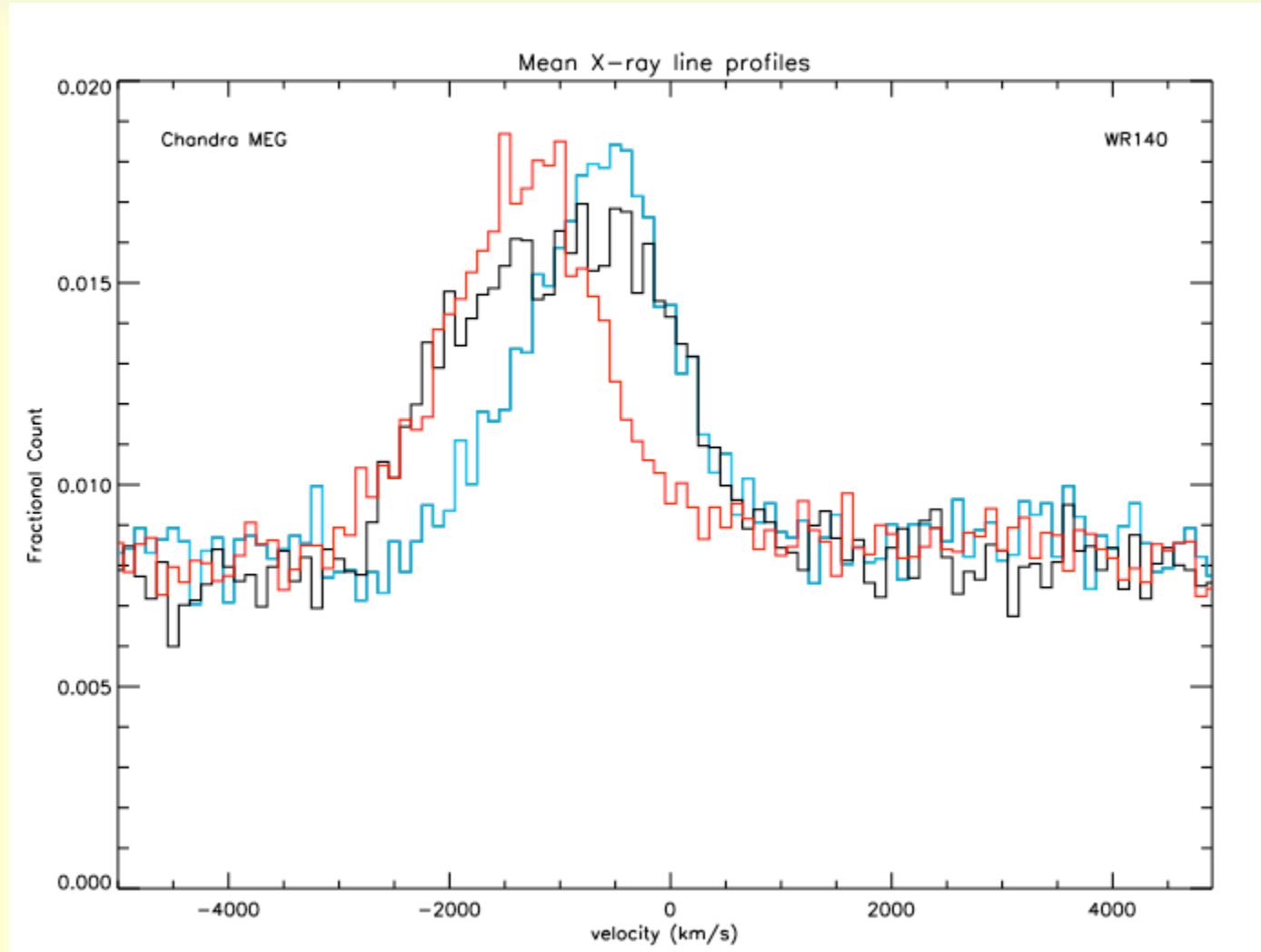
X-rays at high resolution

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## Chandra X-ray mean line profiles



X-rays at high resolution

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## WR140 X-ray implications and complications

- P=2896d ?
- X-ray spectra nearly identical in shape at  $\phi=2.649$  and  $\phi=2.951$
- X-ray eclipse started slowly
  - soon after O-star conjunction
  - well before quadrature
- shocked WC and O5 material mix
- line profiles combine bulk and random components
  - width(IP)
  - affected by stellar eclipses

## Interim lessons from WR25 & WR140

- Eclipses of extended CWB X-ray sources
  - WR wind
  - WR star
- Out of eclipse
  - No obvious flares
  - Significant departures from  $L_X(D) \propto 1/D$
- Collisionless plasma looks collisional
  - shocked WR and O-star material mix
  - collisionless ionization ?